

SOLAR ENERGY EMPLACEMENT DEVELOPER**UNIVERSITY OF HOUSTON**52044
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A preliminary design has been developed for a Lunar Power System (LPS) composed of photovoltaic arrays and microwave reflectors fabricated from lunar materials. The LPS will collect solar energy on the surface of the Moon, transform it into microwave energy, and beam it back to Earth where it will be converted into usable energy.

The Solar Energy Emplacement Developer (SEED) proposed in this report will use a similar sort of solar energy collection and dispersement to power the systems that will construct the LPS.

INTRODUCTION

As we near the 21st century a critical need for alternate power sources becomes more and more apparent. Reliance on primary fossil fuel and nuclear sources in use today subject us and our planet to dangerous consequences including pollution and radioactive waste materials. Solar energy is an alternative that is clean and free, except for the cost of developing the technology and the initial setup of equipment. Solar energy can be collected from any point where the sun is visible, opening the possibility for off-world collection. This possibility will be most feasible if the equipment can be fabricated using materials gathered and processed on the Moon or other planets. All of the component substances necessary for production of solar power facilities exist in the resources of the Moon.

This paper proposes a design for a mobile facility to process lunar materials and construct these necessary components. The system will also use solar energy for component fabrication and operation power.

In 1968 Peter Glaser introduced the concept of using satellites to collect power and transmit it back to earth in the form of microwaves⁽¹⁾. Since this innovative idea was introduced, many other related concepts have been proposed that use power-beaming to support lunar operations and send power back to the Earth from lunar-based arrays. This project applies some of these ideas and introduces new elements into a comprehensive design.

LUNAR POWER SYSTEM

The Lunar Power System (LPS), described in a 1990 study by David Criswell at the University of Houston, makes use of solar energy gathered on the surface of the Moon as an alternate power source for the future⁽²⁾. In its simplest form, the LPS is comprised of four components: Moon-based photovoltaics; microwave reflectors; microwave converters; and Earth-based rectifying antennae. It is constructed using silicon and iron which are common in the lunar soil. Solar arrays are set into a triangular arch shape and placed on the surface of the Moon in parallel rows. These rows of photovoltaics form plots connected to one another by underground wires that lead to a microwave converter box, where electrical energy is transformed into microwave energy and beamed back to Earth.

Silicon will also be used to form glass tubing utilized as structural support for microwave reflectors. The overall system, once on-line, consists of thousands of plots spread over the surface of the Moon. These plots can be located along the lunar limbs to collect sunlight over a 28-day period.

Reflectors can also be placed in orbit around the Moon and Earth. Around the Moon, the reflectors would serve to illuminate the surface during periods of darkness to eliminate power loss. Around the Earth, reflectors will redirect the beams of microwave energy during periods when the plots are not directly on line with the point of reception, enabling power to be transmitted continuously⁽³⁾.

SEED SCENARIO

The Solar Energy Emplacement Developer (SEED) is a set of components which, in the most basic form, use solar energy to accomplish lunar site work. The overall purpose of the SEED is to completely emplace the LPS. The first step in this emplace is to deliver the SEED elements to LEO by a heavy lift launch system. The components are then manifested into a lunar lander containing two habitat modules, two processing modules, a command/control unit, an escape vehicle, and eight rovers described in Table 1^(4,5). The lander is essentially a frame designed to serve multiple functions (Fig. 1). After landing, for example, it can be disassembled and reconfigured to provide a support structure for lunar regolith. Regolith will be used to cover the habitation modules for radiation protection.

The flight-ready lunar lander would be set on a trajectory for an equatorial landing on the Moon. Once the lander nears lunar orbit, solar sails are released and deployed. After deployment of the sails, the lander is automatically guided to an optimum landing site. The rovers then transfer themselves to the surface. Next, the lander is separated into three segments, two of which contain a habitation and processing module and the third, the command/control unit. Upon completion of the separation, the two segments containing modules are loaded onto the rovers. This completed, the components necessary for two LPS operational units are transported to their respective construction sites. The command/control unit is left behind as a communication depot and also serves as a safe haven and emergency takeoff site.

TABLE 1. Element Summary.

No.	Element	Power req. (kW _e)		Mass (T)	Volume (m ³)
		Day	Night		
8	Rovers	20	20	2.5	17.58
2	Habitat Modules	40	20	14.0	200.00
2	Processing Modules	40	40	14.0	200.00
1	Unpressurized Rover	4	20	1.7	15.0
1	Command Module	40	20	9.0	128.00
1	Escape Vehicle			3.5	30.00
Total		144	120	90.2	590.58
Elements	Description				
Rover	Loads and unloads lunar regolith at the processing module. The rover's hopper (17.58 m ³) is capable of transporting 2.93 lunar metric tons of regolith. At 3.2 km/hr, the rover gathers 17.58 m ³ of regolith over a distance of .369 kilometers approximately ten minutes.				
Habitat Modules	Provides safe accommodations for a crew of two for 365 days.				
Processing Module	Provides full production capability of solar arrays.				
Unpressurized Rover	Provides means of local transportation.				
Command Module	Provides safe accommodations for a crew of two for 365 days. It provides a central facility to regulate base communications.				
Escape Vehicle	Provides the capability to transport a crew of six to lunar orbit in the event of an emergency.				
Truss	The space frame provides stability during lunar landing. The frame also can be disassembled and reassembled into different configurations.				

After the habitation modules and the processing plants are placed on the surface at each LPS site, the rovers begin gathering regolith for processing. Rovers at each site deliver material to be processed and take the finished products and place them in an orderly fashion around the plot. When the process is completed at a site, the habitation module and processing plant are reconnected and transported by the rovers to begin construction at the next site.

The SEED project is based on several important assumptions: (1) a heavy lift launch vehicle will be necessary to carry all components to LEO and (2) extensive terrain mapping has been performed on the surface of the Moon to survey candidate sites. Implementation will also require advanced automation and robotic systems with a high degree of reliability. Finally, power beaming, which is still in its infancy, must be advanced to a point that transmitters and receivers can be sufficiently miniaturized to fit into small mobile units.

SOLAR SAILS

The solar sails proposed for this design are helio-gyro configuration (Fig. 2). This configuration is chosen because of its high degree of maneuverability and failure resilience⁽⁶⁾. The sails are used to perform many functions during the construction and operations phase of the LPS.

During the construction phase, at least three sails would be in orbit around the Moon. These would be used to collect and beam power to the SEED components. With three sails in orbit, spaced equally distant from one another, contact with the entire surface of the Moon can be maintained⁽¹⁾.

During the operations phase of the LPS, the sails will serve to illuminate the surface of the Moon where plots are located. To achieve this reflectivity, the sails would be fabricated with an aluminum thin-membrane surface. Also, the reflective area of the sails must be equivalent to the area being illuminated. Similar versions of the sail would also be in orbit around the Earth to reflect microwave beams to receiving antennae.

ROVERS

The rovers are the workhorses of the SEED project (Fig. 3). Each rover is proposed to be approximately 2.5 m × 5 m × 2 m with a weight of approximately 2.5 metric tons and a carrying capacity of 3 lunar metric tons of regolith. The functions of the rover include transportation, material collection, and LPS assembly.

After the rovers transport the habitation modules and processing modules to their selected sites, they must disassemble the frame that supports the modules and reassemble it as shielding over the habitation module. Regolith will be placed on top of the frame to provide radiation protection (Fig. 4).

Next, the rovers begin collecting regolith for processing by deploying a drum device that loosens the regolith and places it on a conveyor system. After sufficient raw material has been collected, the regolith is taken to the processing module where it is unloaded. When processing is complete, the finished solar arrays are placed onto the back of the rover for positioning on the surface of the Moon.

The last step entails assembly of the LPS plot. Arrays are placed on the surface by angling the bed of the rover so that the "heel"

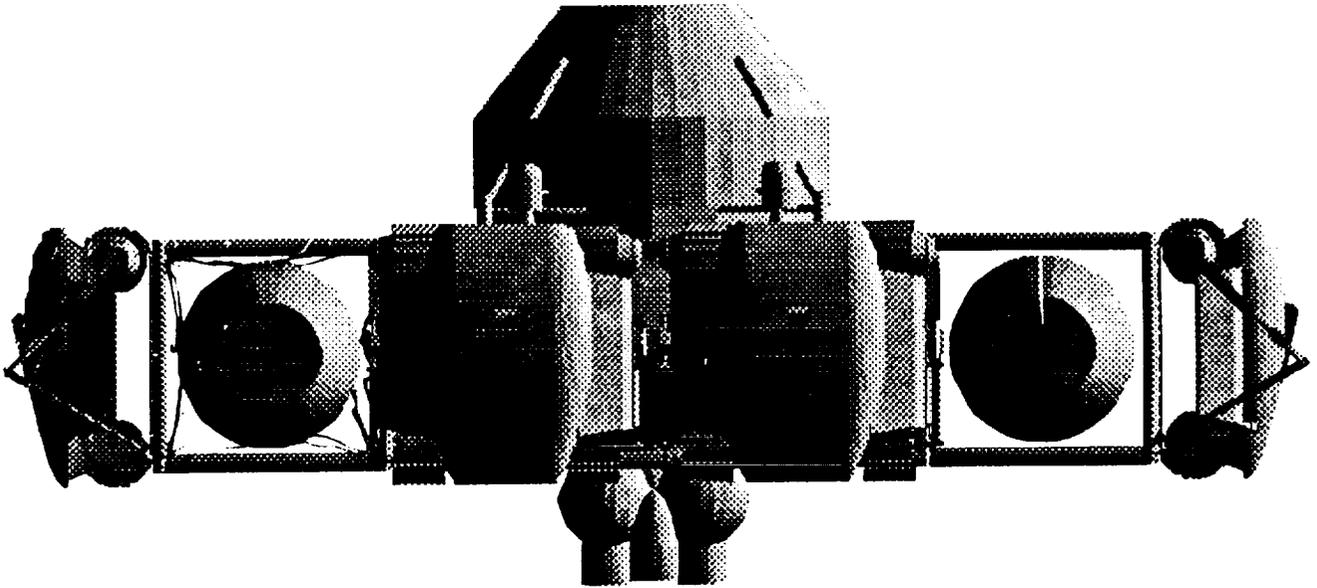


Fig. 1. Lander Configuration.

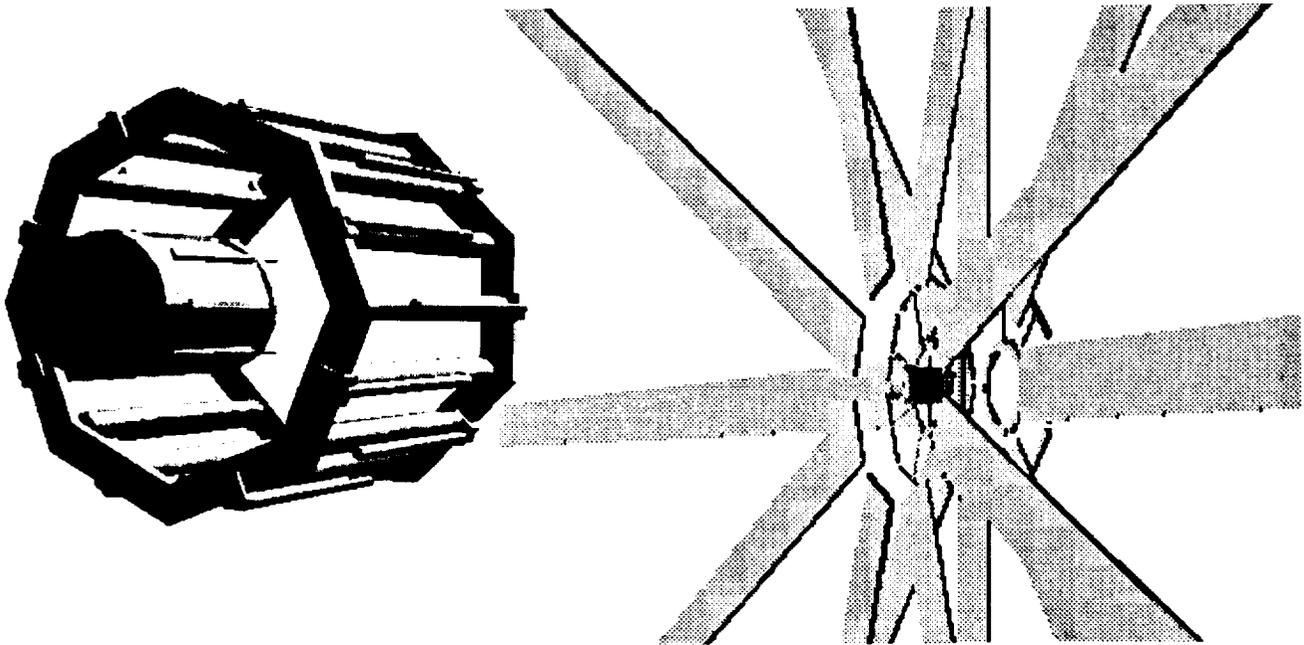


Fig. 2. Solar Sails.

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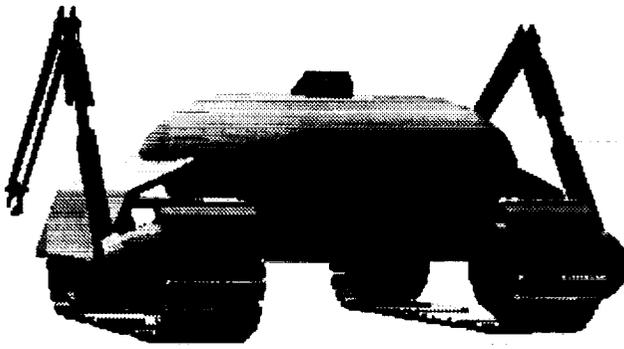


Fig. 3. Rover.

of the arrays is only a few inches from the surface. A manipulating arm then places the "heel" of the arrays, now located on top, onto the surface of the Moon. The rover then moves forward, leaving the array to slide into place. When the end of one set of arrays is reached, the set located directly beneath it is connected by the ends to the previous set. This process continues until the complete set of arrays and reflectors have been deployed. On completion of this operation, the rover moves to a new area and begins collection of regolith.

The rovers can be reconfigured in different ways, according to the functions they are serving. During the collection phase, the bed of the rovers can be completely closed to keep lunar dust from escaping. During the assembly phase, the cover of the rover can be opened to increase the cargo carrying length of the bed and provide a platform for the completed solar arrays.

The power requirements of each rover are estimated at approximately 20 kW based on previous models. This power would drive one motor per track and one motor for the conveyor system to move material in and out of the rover's storage.

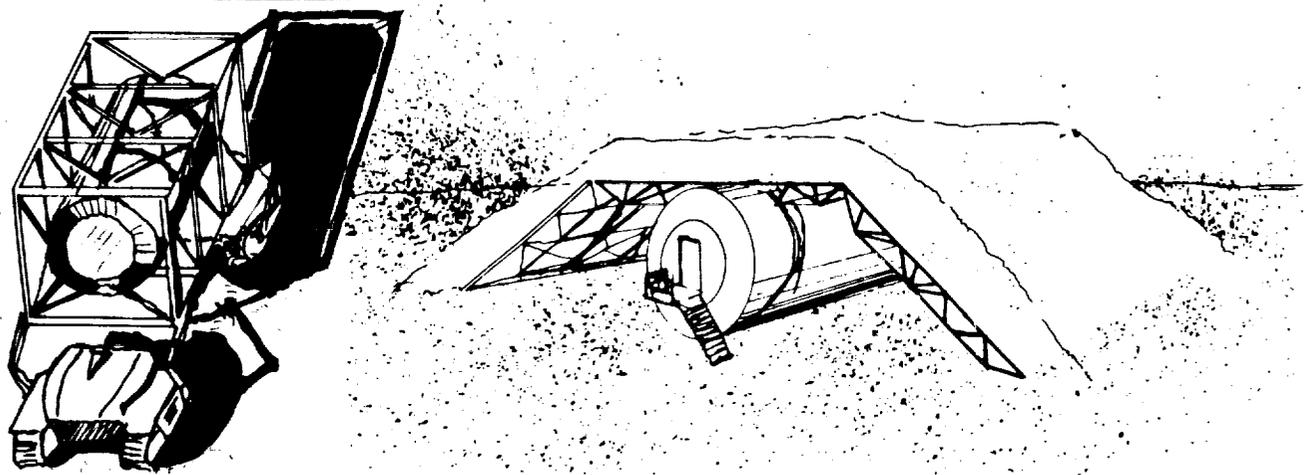


Fig. 4. Module disassembly and habitat shielding.

COMMAND/CONTROL UNIT

The command/control unit provides surface-to-surface communications for extra vehicular activity, rovers, habitat modules, and processing modules. The unit is designed to support a crew of two in a vertical, stacked configuration unlike the horizontal configuration of space-station-type modules. A lower unit (6.7 m diameter and 3.6 m high), contains a health maintenance facility, waste management facility, galley, wardroom, storage, crew quarters, environmental control, and life support systems. An escape vehicle is located on top of the command/control unit with accommodations for a crew of six in the event of an emergency.

HABITATION MODULES

These aluminum modules are based on approximate space-station module dimensions. The modules provide an airlock and dust-off facility and are outfitted with equipment and supplies to support a crew of two for a duration of 365 days. During this stay, the crew would conduct local geologic investigations, undertake experiments in mining the lunar soil, and service and maintain equipment. Each habitation module provides a health maintenance facility, waste management facility, galley, wardroom, laboratory, storage, crew quarters, and environmental control and life support systems.

PROCESSING MODULES

The LPS is a potential solar energy conversion system for terrestrial use. Processing modules support a manufacturing process sequence for the production of the LPS components. The primary function of these modules is to produce photovoltaics, glass fibers, and foamed tubular glass. The process will be expected to operate continuously during the construction of the LPS plots.

In order for the production to proceed effectively, the environment under investigation must produce solar cells with the capability to withstand thermal cycling, reduce the percentage of cell degradation, and produce high-strength structural components. Silicon was selected for the solar cells because of its abundance in the lunar regolith. These solar cells are ultra thin, moderate-efficiency cells.

The following steps are necessary for the production of the silicon cells. Lunar regolith will be unloaded at the processing module where materials needed for solar cell production are separated and extracted within the module. Silicon is then separated and purified to a degree appropriate for producing the solar cells. After being heated, the molten silicon is cooled to form a triangular arch. Due to the absence of moisture in the lunar environment, the strength of silicon may be as high as several million psi allowing the triangular arch structure to be self supporting. Iron is magnetically extracted from regolith and applied to the surface of the solar cell. The solar arrays are then cut to the appropriate length. Measurements will vary depending upon the location of assembly. Upon completion, the solar arrays are transported by rovers to a specified location and interconnected with a wire buried approximately 10 centimeters below the lunar surface. Buried wire avoids stresses on the interconnecting system caused by extreme temperature variations from the lunar day/night cycles⁽²⁾. The wires are then attached to a microwave transmitter that will convert the solar energy into microwaves. This system is assembled so that in the event of photovoltaic cell damage, remaining undamaged cells continue to generate power.

For the solar arrays to maintain efficiency during solar collection, accumulation and adhesion of lunar dust to equipment experienced in Apollo missions, must be eliminated. Lunar dust supports an electrostatic charge under ultraviolet irradiation⁽⁷⁾. A solution may be to form solar arrays with the same charge on the surface as the charge of the dust, causing the dust to be repelled.

Silicon is also used in the production of glass tubing and glass fibers for the construction of reflectors. Glass tubing will serve as structural support for glass fibers covered with a reflective aluminum surface and woven into a cross-grid of strands placed at intervals of 10 cm. The grid will allow light to pass through to the solar arrays and at the same time reflect microwaves toward Earth. Setup of the reflectors as well as the arrays is performed by the manipulating arms of the rovers.

SITE SELECTION

The site is best located in a relatively flat area, away from major surface variations such as craters. The total surface area proposed for this example is an ellipse measuring 16.25 km by 105.6 km. The reflectors must be aligned so that when viewed from Earth, the components converge to form the aperture or "spotlight."

The site must also contain the necessary resources for the production of components used for power generation. Materials critical for production of solar arrays and microwave reflectors are silicon, aluminum, and iron. These elements are common in many lunar minerals located in the maria. Statistical data from previous Apollo missions concerning the location and abundance

TABLE 2. Resource Utilization.

	Lunar Highlands Soils (%)	Lunar Low-Titanium Mare Soils (%)	Lunar High-Titanium Mare Soils (%)
SiO ₂	45.0	46.4	42.0
TiO ₂	0.5	2.7	7.5
Al ₂ O ₃	27.2	13.5	13.9
FeO	5.3	15.5	15.7
MgO	5.7	9.7	7.9
CaO	15.7	10.5	12.0
Total	99.3	98.3	99.0

TABLE 3. Demo — LPS Base.

Base Parameters	Value
Base area of PV cells per MW _c	0.01
Diameter of transmitter (km)	16.25
Area of one reflector segment (m ²)	217.00
Number of plots and reflectors	1000.00
Surface area of transmission (km ²)	5644.00
Surface area of power plots (km ²)	68.60

of major elements located in the highlands and the maria is summarized in Table 2. David Criswell has estimated the size of a demonstration base facility computed from a previous model of the LPS summarized in Table 3.

In order to minimize stay-time for a crew in the event of an emergency, the site should be located along the equator of the Moon. The equatorial trajectory allows for ascent and descent opportunities every two hours⁽⁸⁾. The SEED, therefore, is proposed to be located along the equator at the limb.

CONCLUSION

Our society needs to develop new means of providing energy and our options are limited. Current approaches are damaging to society, both economically and environmentally. Solar energy may provide an answer to these problems in the future. It is important to begin to create new solutions for collecting the vast source of energy available from space for use on Earth. The SEED is proposed as a possible way to meet energy requirements of the 21st century.

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REFERENCES

1. Cull R.C., Power for the Moon: is microwave power beaming an option?, Second Beamed Space Power Workshop, NASA Conference Publication, CP-3037, pp. 329-342: 1989.
2. Criswell, David, R. and R.D. Waldron, Lunar System To Supply Electric Power To Earth. Paper #900279. Accepted for publication and presentation at 25th Intersociety Energy Conversion Engineering Conference, Reno, Nevada, August 12-17, 1990.
3. Criswell, David R., Extraterrestrial Materials Processing and Construction. Lunar and Planetary Institute. Houston, TX. Final report (30 September 1978) NSR 09-051-001 Mod. No. 24. 1978.

4. National Aeronautics and Space Administration, Lunar Energy Enterprise Case Study Task Force, NASA Technical Memorandum #101652: 1989.
5. National Aeronautics and Space Administration, Exploration Studies Technical Report, Volume III: Planetary Surface Systems, The Office of Exploration, FY 1989 Annual Report, Technical Memorandum 4170, pp. 5-49: March 1989.
6. Mallove, Eugene F. and Gregory L. Matloff, *The Starflight Handbook*, John Wiley and Sons, Inc., New York: 1989.
7. Heiken G. Vaniman, D. and B. French, *The Lunar Sourcebook*, Cambridge University Press, Cambridge Mass., pp 27-34: 1991
8. Hoffman, S., Lunar and Mars Trajectories (and some other stuff), SAIC Space Sciences, Technical Memorandum: 1990.